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Prehistoric Juvenile Rheumatoid Arthritis in a Precontact Louisiana Native Population Reconsidered

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ABSTRACT Descriptions of skeletal pathological conditions evident in the prehistoric Tchefuncte adolescent 16ST1-14883b are clarified. The basis is reaffirmed for assigning to the described pathological conditions a diagnostic perspective of juvenile rheumatoid arthritis or juvenile Lyme disease—a disease that mimics juvenile rheumatoid arthritis in its arthritic presentation—rather than of assigning them as representative of juvenile onset ankylosing spondylitis or other juvenile spondyloarthropathies. A hypothesis (Lewis [1994] Am. J. Phys. Anthropol. *93:*455-475) is restated that 1) the spirochete *Borrelia burgdorferi* was the infectious agent responsible for prevalence of adult rheumatoid arthritis in prehistoric southeastern Native American populations, 2) that *B. burgdorferi* is a possible cause of the arthritis evident in individual 16ST1-14883b, and 3) that antibodies to *B. burgdorferi* provided partial immunity to the related spirochete *Treponema pallidum* for the 16ST1 precontact Tchefuncte population from Louisiana, protecting them from severe treponemal response. Given the probable widespread existence of Ixodid tick vectors for *B. burgdorferi* in prehistoric North America, coupled with the existence of treponematosis, it follows that the transition of Native American hunting-gathering economies to more sedentary economies would predictably be linked to an increased incidence of treponematosis due to the loss of benefits of the above-stated partial immunity. In other words, as prehistoric Native American exposure to tick vectors for *B. burgdorferi* decreased, susceptibility to treponematosis increased. Inferences regarding biological controls interacting with and influencing prehistoric Native American migration patterns are suggested from the link of *B. burgdorferi* to an Ixodid tick common to northeast Asia. Am J Phys Anthropol 106:229–248, 1998.

The description of skeletal pathological conditions in an isolated historic case of juvenile rheumatoid arthritis in a 7-year-old girl (HTH-2036) proffered by Rothschild et al. (1997) is welcomed by researchers endeavoring to evaluate disease presence in archaeological contexts. A probable case of juvenile rheumatoid arthritis in an adolescent prehistoric partial skeleton (recovered from a Louisiana coastal shell midden dated ca. 2,000 BP) 16ST1-14883b has been described (Lewis, 1991a,b, 1992a,b, 1994a,b). It is of interest to determine how Lewis' case measures up to the singular historic case reported for HTH-2036 (Rothschild et al., 1997).

Rothschild et al. (1997) take special care to compare and contrast the bony lesions of

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juvenile onset ankylosing spondylitis and other juvenile spondyloarthropathies to those of juvenile rheumatoid arthritis (JRA). They present an argument that juvenile onset ankylosing spondylitis and other juvenile spondyloarthropathies would have very similar osseous involvement to that found in JRA to the extent of being nearly indistinguishable in an archaeological context. However, Rothschild et al. (1997) do agree that a described presumptive case of prehistoric JRA for M11-2023, dated AD 900–1050 and aged 12–15 years, reported for South America by Buikstra et al. (1990), does comply with a suite of characteristics that suggest the diagnostic perspective of JRA assigned to this prehistoric individual is correct. Rothschild also supports a presumption that the prehistoric case GQ391, an adult male, reported by Hawkey (1997) from Gran Quivira, New Mexico (AD 1550–1672) exhibits skeletal pathological conditions which conform to a condition referred to as juvenile chronic arthritis, a term that encompasses juvenile onset forms of both rheumatoid arthritis and spondyloarthropathy. However, Rothschild et al. (1997) indicate that no report of a presumptive case of JRA for prehistoric North America exists and render no opinion regarding the assessment of pathological conditions for 16ST1-14883b (Lewis, 1994a,b). Therefore, this article will seek to clarify and expand on descriptions of skeletal pathological conditions of 16ST1-14883b previously reported and reaffirm the basis for assigning to this prehistoric individual a diagnostic perspective of JRA or a disease that mimics JRA in its arthritic presentation, namely Lyme borreliosis. In addition, reasons are presented for not designating observed pathological conditions in 16ST1-14883b as representative of juvenile onset ankylosing spondylitis or other juvenile spondyloarthropathies.

BACKGROUND INFORMATION

16ST1-14883b is one of 58 partial human skeletons recovered in 1941 from two adjacent Tchefuncte shell middens located on the north shore of Lake Pontchartrain, St. Tammany Parish, Louisiana (Ford and Quimby, 1945; Lewis, 1991b). The majority of these skeletons represent bundle burials of isolated individuals. In only eight cases out of the 51 proveniences examined, including 14883a and 14883b, was an indication found of two people within a burial. Examination of pathological conditions evident in this collection (Lewis, 1991b, 1994b) suggested the prevalence of mild forms of treponematosis, as well as the presence of conditions such as ear exostoses and mild forms of iron deficiency anemia; one probable case of JRA was discerned. In addition to human bone, the middens contained bone representing 40 vertebrate taxa (a minimum number of individuals of 256) with white-tailed deer comprising approximately 59% of the faunal assemblage total and 90% of the worked animal bone total (Lewis, 1997). Pottery present in the middens suggests the merging of a sedentary lifestyle with a hunting/gathering economy. This article will focus on the one case of probable JRA and examine the interrelationships of JRA with Lyme borreliosis, with the dominant presence of white-tailed deer, with a prevalence of treponematosis, and with the presence of iron deficiency anemia in the 16ST1 collection.

MATERIALS AND METHODS

Following the reconvening and reconstruction of 16ST1 skeletons, a suite of the more commonly occurring measurements available in the collection were taken in order to place the skeletons in relation to others in the burial population, to aid in assignment of age and sex, and to affirm the integrity of individual burials (Lewis, 1991b). Multiple skeletal indicators were used to establish age and sex for these individuals following published guidelines (e.g., Lovejoy, 1985; Lovejoy et al. 1985a,b; Steele and Bramblett, 1988; McMinn and Hutchings, 1985; Meindl and Lovejoy, 1985; Meindl et al., 1985; Mensforth and Lovejoy, 1985; Walker and Lovejoy, 1985). Skeletal pathological conditions were observed on a macroscopic level and compared to published reports. Augmenting these macroscopic observations, x-rays were taken of selected bones. Ground sections of six diseased tibiae contributed information on the nature of the treponemal infection present.

RESULTS

Bones present in the 16ST-14883 burial appear to represent two individuals. The first individual, 16ST1-14883a, falls within an age group of 50+ by tooth wear, but within a 40–50 range by cranial sutures. Although judged by the author to be an adult female, 16ST1-14883a is one of the larger females within the burial population, with well-developed musculoskeletal stress markers. 16ST1-14883a has representation of bones of the cranial vault and six permanent teeth, and limb bones including a right humerus, left and right ulna, right femur, and right tibia. The second individual, 16ST1-14883b, is judged by the author to be a juvenile within a 10–20 age group, with an approximate age of 18 years based on epiphyseal fusion and an erupted third molar. Measurements relating 16ST1-14883b to the range of measurements for the burial population as a whole indicate this adolescent to be one of the smaller individuals in the 16ST1 burial population. 16ST1-14883b is represented largely by limb bones and in addition a partial lumbar vertebra, a sacral fragment, a clavicle, and a molar tooth. The following descriptions will focus on the skeletal pathological conditions apparent in 16ST1-14883b.

Appendicular skeleton 16ST1-14883b

Upper limb. *Right humerus.* The midshaft is present. This extremely gracile humerus shaft exhibits an underdeveloped, barely discernible deltoid tuberosity. A circular lytic lesion, measuring approximately 0.8 cm in diameter, is evident on the interior shaft as revealed on radiograph (Fig. 1). This lesion is located distal to the deltoid tuberosity, adjacent to the medullary cavity. The outer cortex is smooth, with no evidence of increased vascularization.

Fig. 1. 16ST1-14883b limb bones collected on radiograph. Note particularly the humerus midshaft (arrow), exhibiting a clearly defined interior lytic lesion, underdevelopment of the deltoid tuberosity, and osteopenia. Radiolucency of the metaphyses of the proximal ulnae and distal tibia is apparent. (Taken at 55KV, 100mA, 1/2 sec, 42" distance.)

Left and right radius. The left radius is represented by the proximal articulation and the mid and proximal shaft. The right radius is represented by the shaft. Ossification of the radial head on the left radius appears complete. Radial tuberosities, attachment site for *m. biceps brachii,* an important flexor of the forearm, are extremely undeveloped, being flat and smooth with a polished appearance (Fig. 2a). The interosseous margins are underdeveloped, contrasting their normal hyperdevelopment for this population.

Left and right ulnae. Both ulnae are represented by the proximal process and shaft. Ossification of the olecranon process is complete. Attachment sites for muscles of both flexion and extension exhibit extreme underdevelopment (Fig. 2b). The olecranon pro-

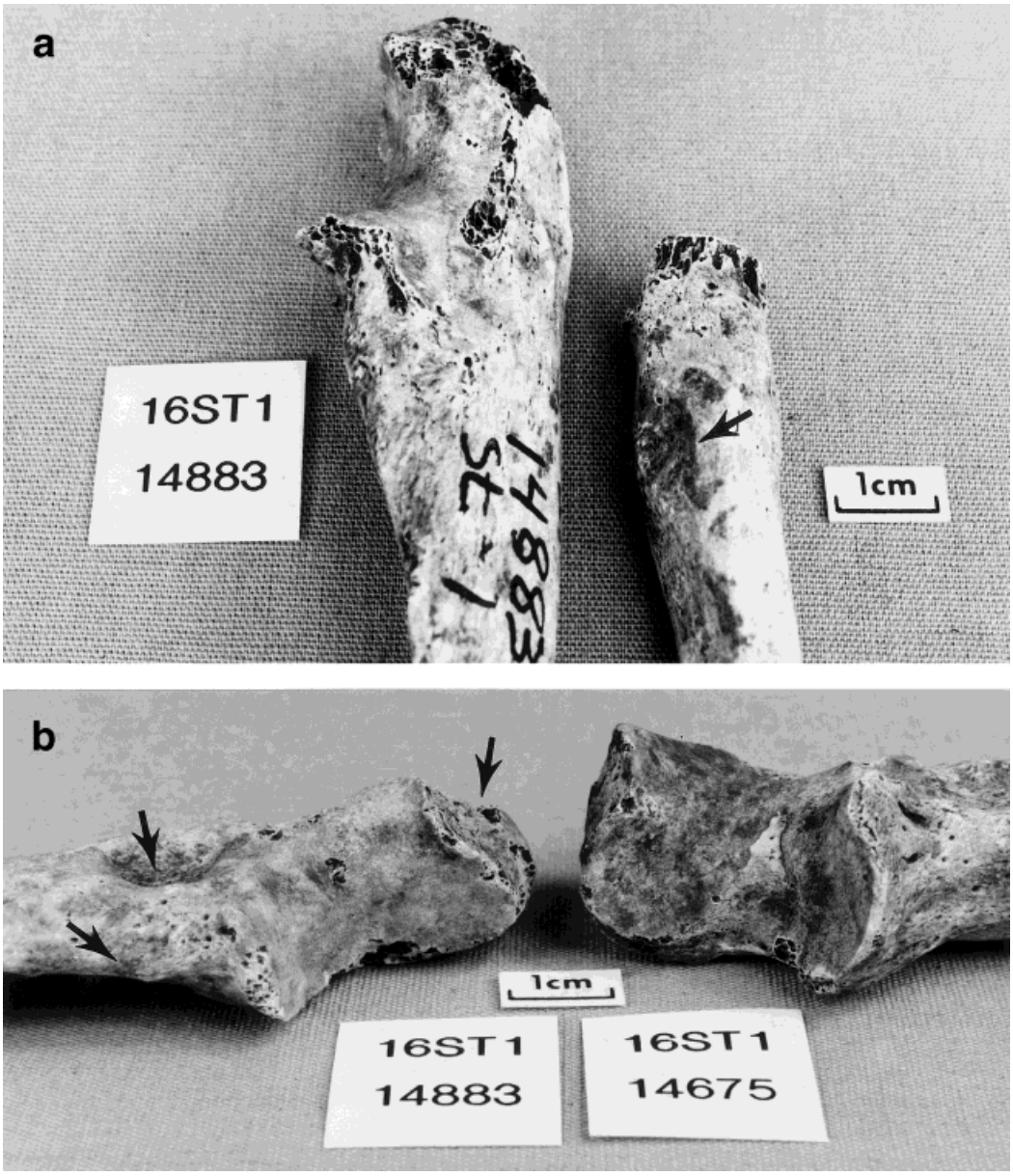

Fig. 2. (**a**) 16ST1, proximal left ulna and radius. Arrow points to underdeveloped radial tuberosity, attachment site for *m. biceps brachii;* (**b**) proximal right ulna of 16ST1-14883b compared to a small female, 16ST1-14675. Arrows point to the narrowed attachment for *m. triceps brachii* on the olecranon process, the sharp emargination at the usual site of the ulnar tuberosity, attachment site for *m. brachialis,* and the cavitation at the usual location of the supinator crest.

cess attachment site for *m. triceps brachii,* an important extendor of the forearm, is undeveloped. The ulnar tuberosity, attachment site for *m. brachialis,* an important flexor of the elbow joint, is extremely undeveloped, forming a sharp emargination rather than a widened region of muscle attachment. A deep smooth cavitation occurs on the right ulna at the usual location of the supinator crest. The supinator crest

on the left ulna is undeveloped, but no cavitation occurs. The midshaft attachment of *m. flexor digitorum profundus manus* is undeveloped; however, there is some development of *m. flexor digitorum superficialis manus* and *m. pronator teres* on the left proximal lateral ulna. Diminution of proximal ulnar articular space is apparent. Growth disturbances are indicated by an elongated and widened appearance of the proximal metaphyses in contrast to the thinned diaphyses (Figs. 1, 2). An erosive process is evident, especially at margins of articulations, and slight periostitis is noted on the metaphyses. The shafts appear bowed (Fig. 3a). Indentations on the ulnae and eburnation of the radial tuberosity indicate that the radius was habitually oriented in a position of pronation on the ulna.

Lower limb. *Left femur.* The left femur is represented by the shaft. The femur is slender and smooth with little evidence of developed bony muscular attachment areas. The linea aspera of the femur, attachment site for powerful adductor muscles, appears as a sharp emargination rather than as an enlarged area of muscle attachment. Attachment site for *m. gluteus maximus* is extremely undeveloped. Attachment sites for *m. pectineus* and *m. vastus medialis* are undeveloped.

Right tibia. The right tibia is represented by the shaft plus distal articulations. Ossification of the distal articulation appears to be complete. The tibia is slender and smooth with little evidence of developed bony muscular attachment areas and has a rounded contour rather than an anterior crest. The interosseous margin is undeveloped. The distal articulation exhibits a deep subchondral erosion suggesting a healed lytic process adjacent to the medial malleolus, a lesion which extends to the anterior margin (Fig. 3b).

Left and right patella. Ossification appears to be complete. The gracile right patella has a deep groove on the articular surface where the medial condyle of the femur would articulate during extreme flexion (Fig. 4a). This groove is present but less developed on the left patella. Attachment site for *m. rectus femoris* is undeveloped. A slight erosive process is evident on the articular surface of both patellae.

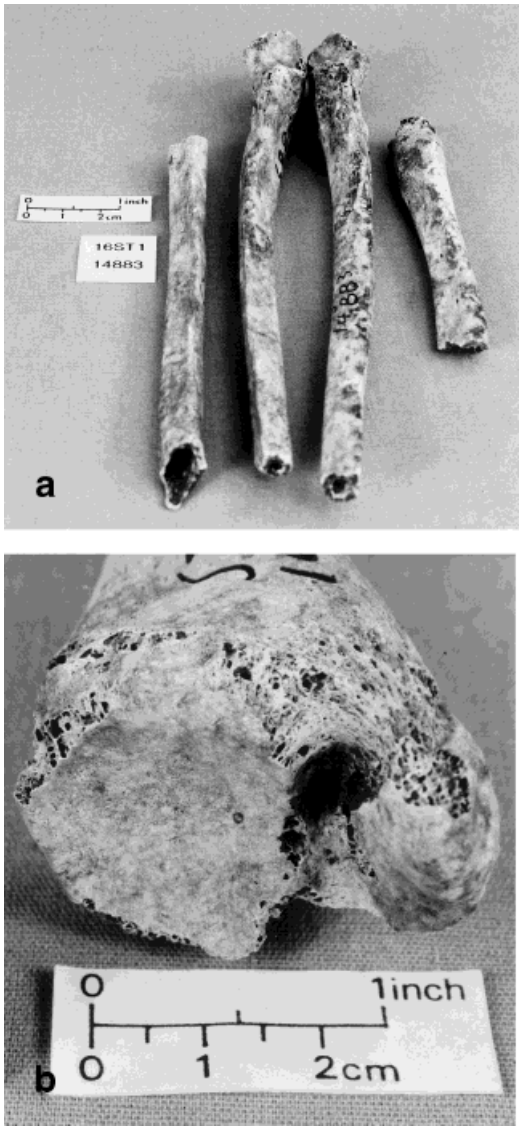

Fig. 3. (**a**) 16ST1-14883b radii and ulnae. Note the bowing, especially on the right ulna, and the lack of development of the interosseous margins, contributing to the thinned diaphyses. (**b**) 16ST1-14883b distal right tibia. Note the articular lesion adjacent to the medial malleolus.

Axial skeleton 16ST1-14883b

Skull. *Third molar.* Absence of wear on the occlusal surface of ?right M^3 is notable; however, presence of an articular facet and

Fig. 4. (**a**) Posterior right patella of 16ST1-14883b compared to an adult male, 16ST1-15127. Arrow points to deep groove on the medial aspect of the patella of 14883b where the femur articulates during extreme flexion. Note its absence on 15127. (**b**) Third molar of 16ST1-14883b. Arrow points to articular facet. Note the lack of occlusal attrition and the deformed, single root.

slight calculus deposition suggests the molar was erupted (Fig. 4b). The single root is small and appears deformed. This molar tooth starkly contrasts the six teeth of the second individual present (16ST1-14883a), which exhibit signs of severe attrition such as the LM_1, which shows wear reaching to the cervical margin, and RPM^4, which is reduced to a stub. The burial population as a whole is characterized by excessive tooth wear.

Vertebrae. *Fifth lumbar vertebra.* Sacralization of the fifth lumbar vertebra has occurred as a result of zygapophyseal fusion (Fig. 5a). The right superior articular facet suggests an erosive process. The centrum is absent; however, remnants of the centrum of the first sacral element suggests that no osseous bridging of the vertebral centra had occurred.

Sacrum. The sacrum appears gracile. As noted above, this right superior sacral fragment exhibits apophyseal fusion to the fifth lumbar vertebra. Present are remnants of the right auricular surface, right centrum, and ala. Incomplete fusion of the first sacral element to the second sacral element is indicated by an epiphyseal remnant (Fig. 5a). A superior auricular surface fragment, including the superior demiface and the apex, appears normal, with no marginal activity noted nor articular erosion, but rather youthful billowing of the auricular surface. Remnants of the superior sacral centrum suggest the absence of fusion of the centrum to the fifth lumbar vertebra, with no ossification of the anulus fibrosus apparent.

Clavicle. The left clavicle has an abnormal, distorted orientation, with reduction of the normal prominent "S" shape for the clavicle (5b). Remnants of the sternal facet suggest that ossification was nearly complete, with presence of a distinctive rim. Attachment for the costoclavicular ligament is developed but narrow and proceeds laterally to a sharp emargination rather than a widened shaft, which contributes to the distortion. The groove for the *m. subclavius* is exceptionally deep. Anteriorly, development of the deltoid tubercle contrasts underdevelopment of the *m. deltoideus* attachment on the right humerus. Posteriorly, the coracoclavicular ligament is underdeveloped: the conoid tubercle is barely discernible and the trapezoid line is flat and smooth. The attachment site for *m. trapezius* is exceptionally thin and elongated and forms a sharp emargination rather than a widened region of muscle attachment.

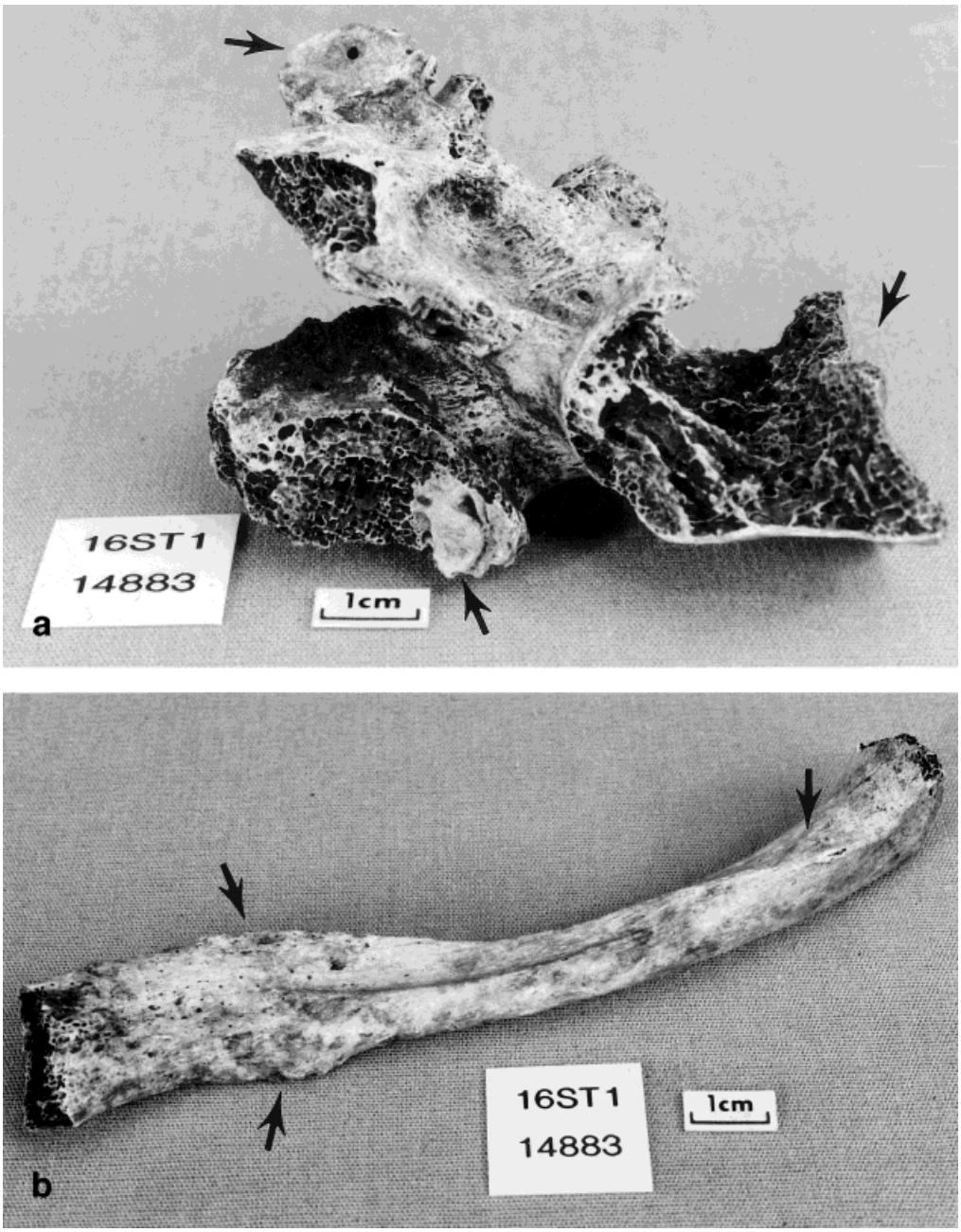

Fig. 5. (**a**) 16ST1-14883b sacrum showing fusion to the fifth lumbar vertebra. Arrow on left points to epiphyseal fragment, indicating incomplete fusion of the first sacral element. Arrow on right points to the location of the auricular surface, not visible in the photograph. Arrow at top points to superior articular facet of the fifth lumbar vertebra (Lewis, 1994b, Fig. 2a). (**b**) 16ST1-14883b left clavicle, inferior view. Arrow on right points to the gracile attachment site for costoclavicular. Arrows on left point to attachment site for *m. deltoideus* (developed) and corococlavicular (undeveloped). A deep groove for *m. subclavius* is present on the shaft.

DISCUSSION

Interpreting 16ST1-14883b

16ST1-14883b exhibits fusion of the fifth lumbar vertebra to the sacrum. In contrast to the abnormal proximal fusion of the articular facets of the first sacral element, distally the first sacral element is separated from the second sacral element with retention of remnants of the epiphysis (Fig. 5a). Since sacral elements do not completely fuse until late adolescence or early adulthood (Steele and Bramblett, 1988), lack of epiphyseal fusion would be consistent with an age of 18 years. Also consistent with a late adolescent age is the presence of billowing on the auricular surface of the sacrum as a mirror image of the auricular surface of the ilium (Lovejoy et al., 1985a).

Remnants of the sternal facet exhibit a granular appearance and presence of a distinctive rim, conforming to an age designation of 18–20 years or slightly older (Steele and Bramblett, 1988). Ossification of the radial head, olecranon processes, and distal tibia conform with a late adolescent age (McMinn and Hutchings, 1985). Premature fusion of bones is a characteristic of JRA (Resnick and Niwayama, 1988), a factor which needs to be recalled in reviewing these age indicators.

An erupted, unworn third molar also suggests late adolescence. The single root of the non-attritial 3rd molar is small and crooked (Fig. 4b). Although occlusal morphology of this molar was used as an age indicator of 16–20 years (Lovejoy, 1985) for this study, lack of development and use of the third molar is consistent with a diagnosis of JRA, which is known to affect severely the growth of and restrict use of the mandibular region, causing micrognathism, limitation of bite, and alterations to the temporomandibular joint (Cassidy, 1997; Pachman and Poznanski, 1997; Resnick and Niwayama, 1988). Rothschild et al. (1997) describe and figure severe involvement of the mandible of HTH-2036.

Although 16ST1-14883b is one of the smaller individuals in the burial population, this placement does not adequately account for the abnormal lack of skeletal indicators for muscular development characterizing 16ST1-14883b, but not characterizing other small individuals. Arm and forearm bones for 16ST1-14883b closely resemble descriptions proffered by Buikstra and colleagues (1990) for a Peruvian case of probable JRA dated AD 900–1050. Diminution of articular space is particularly striking in contrast to another small individual in the 16ST1 burial population (Fig. 2b). The extreme lack of development of bony muscular attachment sites on the limb bones of 16ST1-14883b is consistent with a diagnosis of JRA (Cassidy, 1997; Pachman and Poznanski, 1997; Resnick and Niwayama, 1988). The cavitation at the site of the usual location of the supinator crest on the right ulna (Fig. 2b) closely matches a similar pathology described and figured by Rothschild et al. (1997) for HTH-2036. The suite of forearm attachment sites suggest that the forearm habitually hung loosely in a position of pronation and slight extension, with the hand palm backward and the fingers slightly flexed. The extreme lack of development of the *m. deltoideus* attachment site on the right humerus suggests habitual restriction of movement of the shoulder joint. The internal lesion on the right humerus (Fig. 1) suggests that a blood-borne infection was present in this adolescent at the time of death, but is not indicated as the cause of the observed skeletal growth abnormalities. Inferences from pathological conditions in the proximal ulnae suggest that the humeral condyles were severely affected by pathological conditions mirroring the condition of the ulnae.

On the left clavicle, lack of scapula mobility and arm mobility are indicated by the extreme lack of development of attachments for *m. trapezius,* the trapezoid ligament line, and the conoid tubercle. The cavitation for *m. subscapularis* suggests medial rotation at the shoulder joint was not as restricted as other movements. Development of the attachment for the costoclavicular ligament suggests that axial connections were not as severely affected as shoulder joint connections and movements (Fig. 5b). For an 18-year-old, one would expect much greater development of the attachment for *m. sternocleidomastoideus,* a muscle involved in rotation, flexion, and extension of the head, and

a muscle attachment site usually well developed in this burial population. Development of the *m. deltoideus* attachment site suggests that the upper chest served to compensate for lack of use of the left arm. The abnormal orientation of the clavicle suggests that muscles pulling on the clavicle in opposite directions had not been used enough to exert tension to pull the clavicle into a strong "S" shape. Muscle attachment areas noted on the clavicle in conjunction with a deformed appearance and orientation might be related to compensation for abnormalities and underdevelopment of the humerus, radius, and ulna and compensation for apparent extreme restriction of movement utilizing the upper limb. In contrast to 16ST1-14883b, characteristics of clavicular pathological conditions for other individuals in this burial population tend toward hyperostosis of muscle attachment sites on the clavicle (e.g., Lewis, 1994b, Fig. 6b).

Disturbance of the epiphyseal growth plates in JRA may result in either premature fusion or uneven overgrowth of adjacent bones, which results in a bowing deformity (Fig. 3a). The elongated and widened metaphyses noted on the ulnae and radii (Figs. 1, 2) indicate a disturbance of the epiphyseal growth plates. Abnormal orientations of the radius to the ulna and bowing of the ulnae conform with expectations for JRA.

The deep groove on the right patella suggests long-standing restriction of movement and a habitual flexed position of the right leg (Lewis, 1994b). This groove is not present in other individuals in the burial population, for instance, a large male (Fig. 3a). Restriction of movement is underscored by the underdevelopment of bony muscular attachment sites on the femur and tibia. Although Rothschild et al. (1997) do not describe a groove on the patella for HTH-2036, they include the autopsy report, which recorded, "The left thigh is flexed and adducted and cannot be straightened out. The left leg is flexed on the left thigh and cannot be extended. The musculature, especially over the leg bones, has undergone extreme atrophy" (Rothschild et al., 1997:252). For HTH-2036, Rothschild et al. (1997:256) figure a magnified close-up of the posterior aspect of a patella which indicates "subchondral erosion and unremodeled holes." Although some erosion is noted on the articular surface of the patellae of 16ST1-14883b, the extreme erosive condition noted by Rothschild et al. (1997) for HTH-2036 is not present.

It should be recalled that a 7-year-old would not be expected to have complete fusion of articular joints to the shaft, and thus the articular erosions and epiphyseal erosions figured for HTH-2036 are not always directly comparable to 16ST1-14883b, whose epiphyses were fused to the shaft. The age difference may partially account for the discrepancy in articular erosions, which are severe for HTH-2036 but not as severe for 16ST1-14883b.

The habitual posture suggested by musculoskeletal stress markers for 16ST1-14883b is one of sitting on flexed legs, with the right hip resting on the right ankle joint, a factor which may have contributed to the cavitation in the distal right tibia joint. The arms hung loosely from the side, rotated medially at the shoulder joint with pronation of the radius on the ulna and with the hands palm backward and the fingers slightly flexed. The chest protruded forward.

16ST1-14883b differs from the case of juvenile chronic arthritis reported by Hawkey (1997) for GQ391, in which, by the end of subadulthood, all elbow, hip, wrist, and hand regions were completely ankylosed. The only ankylosing noted for 16ST1-14883b is zygapophyseal fusion of the fifth lumbar vertebra to the sacrum. Similarities between these two individuals exist in that disabilities in both of these individuals would have required the assistance of a care-giver. Hawkey (1997) focuses on the osteobiography of GQ391 and speculates that a compassionate care-giver would have been necessary for this individual to reach young adulthood. For 16ST1-14883b, it is interesting to conjecture whether the other individual in this burial represents the caregiver, and whether the death of 16ST1-14883a necessitated or precipitated the death of 16ST1-14883b. Judged a female by multiple skeletal indicators, 16ST1-14883a had unusually well-developed muscle attachment sites compared to other females in this burial population, which would be consis-

tent with an extended period of care-giving to a crippled individual.

Differential diagnosis

Problems with nomenclature for juvenile chronic arthritis. Nomenclature for juvenile chronic arthritis is problematical. In the United States, it is common to divide juvenile chronic arthritis into 1) juvenile onset adult type rheumatoid arthritis; 2) juvenile rheumatoid arthritis which encompasses polyarticular JRA, oligoarticular (pauciarticular) JRA, and systemic onset JRA; 3) juvenile onset ankylosing spondylitis; 4) other spondyloarthropathies, which include entities such as psoriatic arthritis, Reiter's syndrome, and arthritis of inflammatory bowel disease; and 5) juvenile infectious arthritis, which encompasses entities such as arthritis related to Lyme disease, rheumatic fever, and systemic lupus erythematosus (Resnick and Niwayama, 1988). In Europe the distinction of JRA is usually not adhered to; JRA in this system is generally referred to as juvenile chronic arthritis. Work is in progress to have a uniform system in both the United States and Europe (Pachman and Poznanski, 1997).

Juvenile rheumatoid arthritis. Cassidy (1997) provides the following information on JRA pertinent to 16ST1-14883b, most of which is supported by Pachman and Poznanski (1997) and Resnick and Niwayama (1988): 1) Juvenile rheumatoid arthritis in its polyarticular presentation generally involves symmetrically the large joints such as the knees, wrists, elbows, and ankles, but may also include the small joints of the hands and feet. 2) Arthritis of the apophyseal joints of the spine is common—apophyseal joints of the cervical vertebrae are the focus of involvement, but the thoracic and lumbar vertebrae may also be involved. 3) Sacroiliac arthritis is not common, and when it occurs is not characterized by the reactive sclerosis that is typical of ankylosing spondylitis. 4) Asymmetric temporomandibular joint involvement is common and leads to limitation of bite and micrognathia. 5) In JRA's oligoarticular (pauciarticular) presentation, asymmetric involvement of the knees or ankles is the focus of disturbance, and involvement of the hip is almost never present at onset. 6) For JRA in general, atrophy of muscles around infected joints follows established disease—atrophy of the extensor muscles and later of the flexors begins early in the disease course; inflammation of the tendon sheaths is common at the wrists and ankles, and loss of extension of the fingers can result from involvement of the flexor tendon sheaths. 7) Growth disturbances are common—premature fusion of epiphyses is characteristic, and disturbance at growth centers can lead to either stunting of growth or conversely overgrowth of affected bones; uneven growth patterns can result in bowing of bones. 8) Osteopenia is characteristic, and periostitis may occur; in disease of long duration, marginal erosions and narrowing of articular space may occur. 9) In addition, uveitis leading to blindness is a common complication for girls with early onset oligoarthritis.

Rothschild et al. (1997:262) provide the following skeletal indicators for JRA: 1) peripheral articular marginal and subchondral erosions; 2) axial (e.g., zygapophyseal or sacroiliac) joint erosions; 3) fusion of axial (cervical zygapophyseal) and/or peripheral joints; 4) premature epiphyseal closure and/or ballooned epiphyses; 5) growth retardation with underdeveloped (short and overtubulated) long bones; 6) short mandibular rami with underdeveloped condyles, producing micrognathia; and 7) demineralization (osteopenia). They also suggest that an eroded, deformed ulna is of unclear diagnostic significance and state "Among the characteristics helpful in recognizing juvenile rheumatoid arthritis, only premature epiphyseal closure and/or ballooned epiphyses, growth retardation with underdeveloped (short and overtubulated) long bones, and micrognathia would not be anticipated in juvenile spondyloarthropathy" (1997:262).

For 16ST1-14883b, growth disturbances are directly discerned and micrognathia and disuse of the mandibular region is indirectly indicated. Deformed ulnae are important diagnostic considerations for 16ST1-14883b. The pattern of joint involvement, muscle atrophy, and osteopenia conform with expec-

tations for JRA. Despite the concentration of pathological conditions in the cervical vertebrae of M11-2023 and HTH-2036, Buikstra et al. (1990) and Rothschild et al. (1997) report changes in articular facets throughout the vertebral column. Cervical vertebrae are not present for burial 16ST1-14883b. However, involvement of the fifth lumbar vertebra would not preclude 16ST1-14883b from a diagnosis of JRA. Although thoracolumbar involvement for JRA is not typical, it is not unknown and might be an outcome of a progressive, long-standing disease course. Although Rothschild et al. (1990) report the absence of zygapophyseal fusion in adults with rheumatoid arthritis, clearly zygapophyseal fusion is a complication of JRA.

Juvenile ankylosing spondylitis. One of the main problems in the case of 16ST1-14883b is the differential diagnosis between ankylosing spondylitis and JRA. Pachman and Poznanski (1997) note that juvenile spondyloarthropathy often involves less than four joints, frequently those below the waist. Cassidy (1997) notes that the child with juvenile ankylosing spondylitis will usually exhibit the onset of arthritis in the lower extremities, accompanied by enthesitis with bony growth at sites of tendon and ligament insertions. Remittent oligoarthritis and noninvolvement of the wrists or joints of the hand is to be expected. Rothschild and colleagues (1990, 1991b, 1997) distinguish the bony lesions of adult rheumatoid arthritis from the erosive lesions of spondyloarthropathy on the basis of the latter's tendency to lay down reactive bone. They describe spondyloarthropathy as characterized by erosive joint disease, ossification of sites of tendon, ligament, and joint capsule insertion, and a tendency to spine and sacroiliac fusion. They suggest that spondyloarthropathy is associated with paucity of bony trabecular loss in contrast to rheumatoid arthritis, which is characterized by osteopenia. They also confirm the sparing of the sacroiliac joint in adult rheumatoid arthritis, in contrast to a tendency toward sacroiliits in spondyloarthropathy. Resnick and Niwayama (1988) distinguish JRA from spondyloarthropathy on the basis of frequent involvement in the latter of the sacroiliac joint, lower incidence of cervical alterations, sparing of the articulations of the hands and the wrists, and the absence of severe osteoporosis and growth disturbances. Enthesities of the sternal joints would be expected in an advanced case of juvenile onset ankylosing spondylitis (Arriaza, 1993; Arnett, 1997; Ball, 1993; van der Linden, 1997). Enthesities are common to juvenile ankylosing spondylitis, whereas muscle atrophy and underdevelopment of bone at muscle attachment sites is common to JRA.

Although the lumbar vertebra of 16ST1-14883b exhibits reactive bone at apophyseal locations, most sites of tendon, ligament, and joint capsule insertion in 16ST1-14883b exhibit underdevelopment of bone and a notable absence of reactive enthesial remodeling. The sacroiliac joint does not exhibit any signs of fused bone or other signs of sacroiliitis. Enthesities of the sternal joints is not indicated for 16ST1-14883b. A hallmark of juvenile-onset ankylosing spondylitis is pathology of the sacroiliac joint (Arriaza, 1993; Arnett, 1997; Ball, 1993; Cassidy, 1997; van der Linden, 1997), a joint which appears to be normal in 16ST1-14883b. For ankylosing spondylitis, involvement of the vertebral column in an ascending order with syndesmophyte formation often follows sacroiliac involvement, a condition which sometimes leads to "bamboo spine." Although fusion of the fifth lumbar vertebra to the sacrum might indicate ankylosing spondylitis, the mode of fusion in 16ST1-14883b suggests otherwise. For 16ST1-14883b, lack of syndesmophyte formation or other indicators of vertebral centra fusion would be inconsistent with expectations for a highly diseased vertebra of a person suffering from ankylosing spondylitis.

Additional spondyloarthropathies and other considerations. Differential diagnosis derived from clues taken from an incomplete skeleton can point toward negation of additional diseases with similar skeletal pathological conditions. Psoriatic arthritis is characterized by sacroiliitis and asymmetric destructive articular involvement, especially of the distal interphalangeal joints (Resnick and Niwayama, 1988). Arthritis of inflammatory bowel disease is

associated with spinal, sacroiliac, and peripheral joint involvement (Resnick and Niwayama, 1988). Although age-of-onset of Reiter's syndrome (15–35 years of age) conforms with 16ST1-14883b, Reiters syndrome is characterized largely by asymmetric arthritis of the lower extremities, especially the knee and ankle (Arriaza, 1993). Reactive arthritis often is accompanied by new bone development at sites of ligament and tendon attachment and involvement of the sacroiliac joint (Resnick and Niwayama, 1988). Erosive joint disease in ankylosing spondylitis, psoriatic arthritis, Reiter's syndrome, and bowel-disease associated arthritis is, for almost all individuals, asymmetric and pauciarticular with periostitic or enthesial reaction, bony ankylosis, and occasional sclerosis (Rothschild et al., 1988). Diffuse idiopathic skeletal hyperostosis (DISH) is associated with a later age-of-onset, prominent syndesmophytes, and enthesopathy (Arnett, 1997). The arthritis of systemic lupus erythematosus is usually nondeforming and nonerosive (Cassidy, 1997). Both hemophilia and juvenile chronic arthritis can cause changes in patellar shape (Resnick and Niwayama, 1988). However, Buikstra et al. (1990) report that hemophilic arthritis, which would induce similar responses in the knee and elbow region and is associated with premature epiphyseal fusion, is not known to cause vertebral fusion. Rheumatic fever, although involving joints, is not characterized by bony changes (Buikstra et al., 1990).

Similarities of JRA and Lyme disease. There is much still to be learned about skeletal pathological conditions of Lyme disease, which was first described in the mid-1970s in a group of children near Lyme, Connecticut, with symptoms of JRA. In 1984, Burgdorfer isolated a spirochete from what was then referred to as the *Ixodes dammini* tick found in North America. This spirochete, *Borrelia burgdorferi,* is the causative agent for Lyme disease (Burgdorfer et al., 1989). It was subsequently determined in this decade that *I. dammini* is con-specific and thus synonymous with *Ixodes scapularis,* the black-legged deer tick common to the southeastern United States (Oliver et al., 1993c).

Arthritis associated with Lyme disease (Lyme borreliosis) does show similarities to rheumatoid arthritis. For instance, Sigal (1989:153) notes that one effect of Lyme disease is an arthritic-like response similar to rheumatoid arthritis but contrasting rheumatoid arthritis by "striking deposition of fibrin in and on the hyperplastic villi of the synovium." Sigal (1993) indicates that for late or chronic Lyme disease, musculoskeletal manifestations include polyarthralgia, true inflammatory disease (poly-, oligo-, and mono-articular), tendinitis, bursitis, and fibromyalgia. Arthritis occurs in the third stage of Lyme disease in 60% of cases, but approximately 10% of patients develop a chronic arthritis which resembles other forms of inflammatory arthritis (Lahesmaa et al., 1994). "The chronic arthritis clinically and pathologically resembles rheumatoid arthritis; spirochetes have been visualized in synovial biopsies from such patients" (Schmid, 1989:S1467). Rahn and Malawista (1993) indicate that the adult expression of Lyme arthritis can mimic the large knee effusions of Reiter's syndrome or resemble symmetrical polyarthritis in adults. Arthritis associated with Lyme borreliosis usually affects only a few joints at a time, and recurrent attacks are usually separated by longer periods of remission (Steere, 1997). However, Cassidy (1997) notes that occasionally a chronic polyarthritis with associated erosions occurs in children with Lyme arthritis.

Lyme arthritis and JRA share a number of clinical features, among them a predilection for large joints (Saulsbury and Katzman (1990). In children, chronic arthritis associated with Lyme borreliosis most closely resembles juvenile pauciarticular expressions of JRA (Steere, 1997). Zemel (1992) reports that the arthritis of Lyme disease in children is typically acute, oligoarticular, and of brief duration. The knee is the most commonly affected joint, but other joints include the elbow, wrist, hip, shoulder, and ankle; temporomandibular and sternoclavicular arthritis rarely occur in children, and small joints of the hands tend to be spared.

Relating 16ST1-14883b to the differential diagnosis. The pattern of muscle wasting throughout the skeleton, polyarticular involvement, joint abnormalities, diminution of articular space, and growth disturbances evident in 16ST1-14883b closely coincides with a probable case of JRA reported by Buikstra et al. (1990). In addition, of the seven characteristics listed by Rothschild et al. (1997) as helpful criteria for recognition of JRA in the archaeological record, direct or indirect evidence from 16ST1-14883b suggests at least partial compliance with all seven characteristics. Zygapophyseal fusion in the absence of sacroiliitis, absence of syndesmophyte formation, and absence of generalized enthesitis also support a diagnosis of JRA for 16ST1-14883b rather than any of the various spondyloarthropathies. Differential diagnosis suggests that either JRA or Lyme borreliosis would exhibit skeletal pathological conditions similar to those evinced by 16ST1-14883b.

Interaction of treponematosis and Lyme borreliosis

From the following observations, a hypothesis was presented (Lewis, 1994a,b) that the relatively mild expression of treponemal infection within the 16ST1 Tchefuncte burial population resulted from partial immunity to the spirochete *Treponema pallidum,* as derived from exposure to the spirochete *B. burgdorferi:* 1) Forms of both juvenile rheumatoid arthritis and adult rheumatoid arthritis have known correlations to the disease processes of Lyme borreliosis. 2) The bacteria causing Lyme borreliosis is transmitted by *I. scapularis,* a tick common to deer as well as other woodland animals in the southeastern United States. One would therefore expect the 16ST1 Tchefuncte Indians, whose principal prey was deer (Lewis, 1991b, 1997) to have been frequently exposed to the bacterial agent for Lyme borreliosis, the spirochete *B. burgdorferi.* 3) Frequent presence of indicators of treponemal infection within the 16ST1 Tchefuncte burial population suggests that these Native Americans were exposed to another bacterial spirochete, *T. pallidum.* 4) The bacterial spirochetes *B. burgdorferi* and *T. pallidum* are so closely related as to provide partial cross-immunity. 5) A developing body of literature suggests that pathogens causing Lyme borreliosis or a similar disease were widespread in North America in prehistoric times. Figure 6 summarizes some of the maze of interconnections relating to the above-stated hypothesis.

Magnarelli et al. (1990) reported on the cross-reactivity of nonspecific treponemal antibody in serologic tests for Lyme disease. As explained by Sigal (1993:83): "An antibody may very effectively bind its intended target on the organism causing the current infection, and yet the same immunoglobulin molecule can bind to another related organism, thus preventing or minimizing future infections. Thus it should not be surprising that normal individuals have antibodies that can bind to *B. burgdorferi* even though that person may never have been exposed to LD (Lyme Disease), perhaps produced in response to other spirochetes or to gut flora." What was hypothesized by Lewis (1994b) was the reverse of this process, that *B. burgdorferi* provided partial immunity to other spirochetes. A later report (Kantor, 1994) lends support to this hypothesis, referring to the close relationship of *T. pallidum* and *B. burgdorferi.* If exposure to *B. burgdorferi* was a relatively common occurrence for the 16ST1 Tchefuncte population, as indicated by the species content and enumerations in the 16ST1 faunal analysis (Lewis, 1991b, 1997), then the above-stated hypothesis extends to include the possibility that the JRA indicated for 16ST1-14883b might be an expression of the disease known as Lyme borreliosis or Lyme disease.

Disruption of a long-established economy based on hunting-gathering in woodland environments would have correspondingly disrupted a source of natural immunity to treponemal infection derived from exposure to deer ticks, making the Tchefuncte Indians and other Native Americans in economic transition more susceptible to treponematosis. A study in Japan focusing on the sera of hunters in Hokkaido showed that those who went gathering edible wild berries had significantly higher antibody to *B. burgdorferi* than those who did not (Kubo et al., 1992). Distribution of vector tick species for *B.*

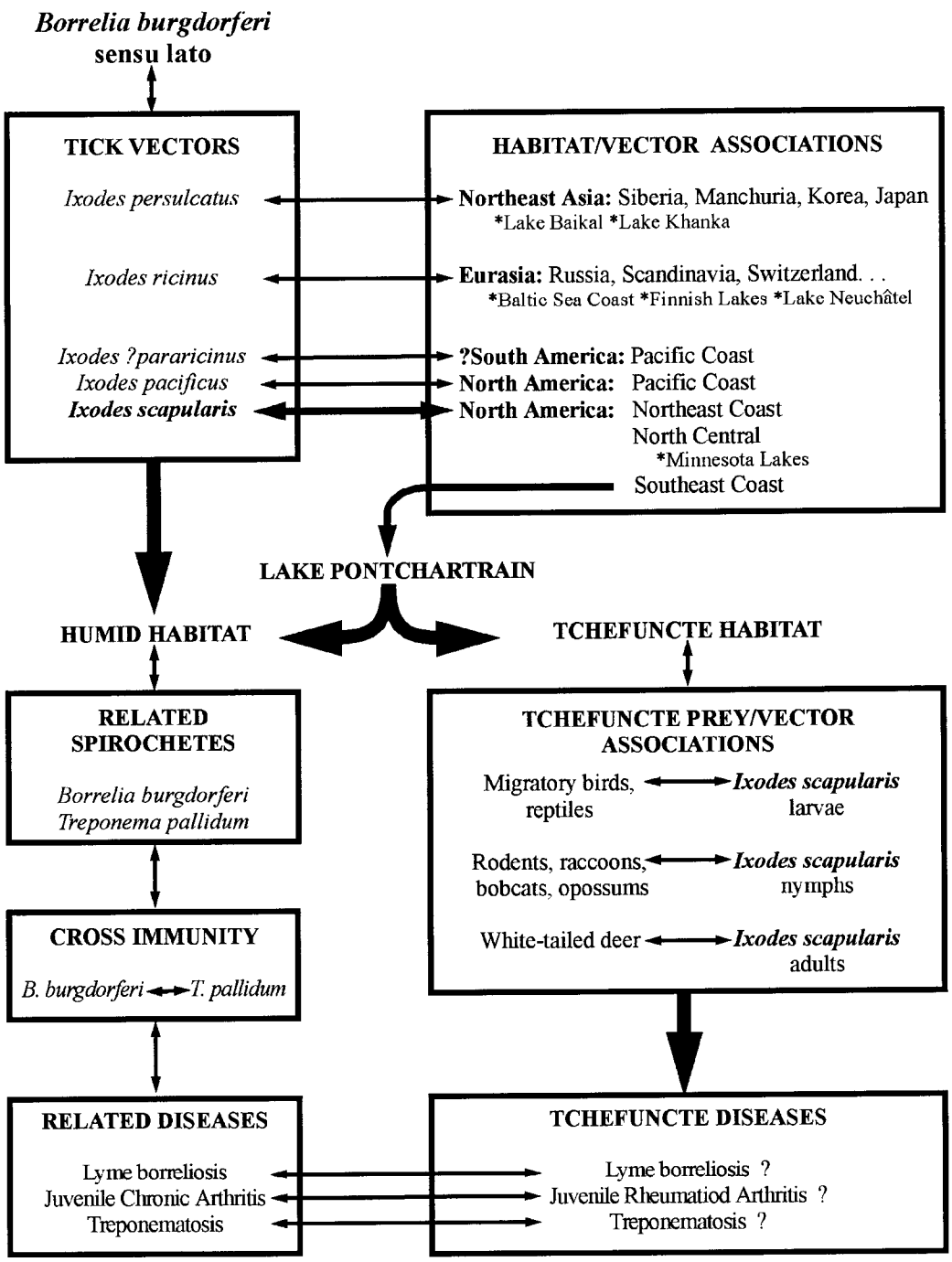

Fig. 6. Flow diagram of interconnections linking pathogens, tick vectors, habitat, and prey to possible disease presence at the 16ST1 Tchefuncte site with inferences for biological controls influencing Native American migration patterns from a focus in Northeast Asia. Derived from information presented in Lewis (1994a,b) and the present text. Examples of appropriate references are the following: Ai et al., 1990; Anan'eva et al., 1991; Anderson, 1989; Anderson et al., 1986, 1990; Azulay et al., 1991; Barbour et al., 1996; Brown and Lane, 1992; Burgdorfer et al., 1989; Dattwyler et al., 1989; Dekonenko et al., 1988; Durden et al., 1993; Ewing et al., 1994; Goldings et al., 1991; Guzman and Neira, 1993; Hofmeister and Childs, 1995; Jaenson, 1991; Johnson, 1993; Kantor, 1994; Korenberg, et al., 1993; Kubo et al., 1992; Lahesmaa et al., 1994; Lewis, 1991b, 1994a,b, 1997; Luckhart et al., 1992; Magnarelli et al., 1995a,b; Magnarelli et al., 1990; Mahnke et al., 1993; Mathiesen et al., 1997; Merbs, 1992; Nakao et al., 1992; Need and Escamilla, 1991; Oliver, 1996; Oliver et al., 1993a,b,c; Ouellette et al., 1997; Park et al., 1993; Piesman, 1993; Probert et al., 1997; Saulsbury and Katzmann, 1990; Schmid, 1985, 1989; Sigal, 1989, 1993; Simon et al., 1991; Slajchert et al., 1997; Smith et al., 1996; Sood et al., 1997; Stamm and Parrish, 1994; van Dam et al., 1997; Walker et al., 1991a,b; Wehinger et al., 1995; Wikel et al., 1997; Xu et al., 1996; Zeidner et al., 1996; Zenker and Rolfs, 1990; Zhang, 1991.

burgdorferi sensu lato might overlap with and indicate the nature and extent of distribution of prehistoric treponematosis and rheumatoid arthritis and shed light on the interaction of biological controls influencing prehistoric migratory patterns from a focus in northeast Asia. It is interesting to note that a known tick vector for *B. burgdorferi* sensu lato is *Ixodes persulcatus,* known principally from Siberia, Manchuria, Korea, Japan, and Asian parts of Russia (Anan'eva et al., 1991; Dekonenko et al., 1988; Nakao et al., 1992; Park et al., 1993; Zhang, 1991). Nakao et al. (1992) suggests that variants of *B. burgdorferi* invaded northern Japan, together with the vector ticks in the glacial epoch when the Japanese islands were connected to Siberia. Merbs (1992) reports on the probable presence of pathogens responsible for Lyme disease in prehistoric America. The role of migratory birds in spreading infective ticks (Anderson et al., 1986, 1990; Smith et al., 1996) has important implications for the presence of *B. burgdorferi* at the Tchefuncte site, located near the endpoint of the Mississippi flyway. Recent work establishing the heterogeneity of *B. burgdorferi* in the United States (e.g., Mathiesen et al., 1997) supports a concept of the antiquity of this organism in North America. *B. burgdorferi* sensu lato has concentrations in regions such as Lake Baikal, Siberia; Lake Khanka, Manchuria; lake regions of Minnesota and Wisconsin, and coastal regions of the east and west coast of the U.S. (Ai et al., 1990; Brown and Lane, 1992; Dekonenko et al., 1988; Gill et al., 1993; Mahnke et al., 1993). Prehistoric Lake Pontchartrain, Louisiana, with an abundant white-tailed deer population and corresponding vector ticks and reservoir host fauna for *B. burgdorferi* (e.g., Durden et al., 1993; Levine et al., 1997; Luckhart et al., 1992; Magnarelli et al., 1995a,b; Mahnke et al., 1993; Oliver, 1996; Ouellette et al., 1997; Slajchert et al., 1997; Wehinger et al., 1995) would have been an environment compatible for proliferation of *I. scapularis* and *B. burgdorferi.* In addition, another southeastern tick, *Amblyomma americanum,* the lone star tick, has been linked to Lyme disease or a disease similar to Lyme disease (Barbour et al., 1996; Goldings et al., 1991).

A proliferation of reports in recent years regarding Lyme disease have concentrated on the identification of outer surface proteins or outer membrane proteins of the spirochete *B. burgdorferi* sensu lato that might elicit an immune response or be candidates for a vaccine (e.g., Bunikis et al., 1996; Fikrig et al., 1997; Hofmeister and Childs, 1995; Lahdenne et al., 1997; Lam et al., 1994; Luke et al., 1997; Magnarelli et al., 1995a; Probert et al., 1997; Šadžiene et al., 1996; Sellati et al., 1996; Wilske et al., 1993), modes by which both the tick and the spirochete evade host immune response and the influence of the length of tick attachment (e.g., Burkot et al., 1994; Indest et al., 1997; Lahesmaa et al., 1994; Piesman, 1993; Shipley et al., 1993; Sood et al., 1997; Straubinger et al., 1997; Wikel et al., 1997; Zeidner et al., 1997), the role that iron deficiency or vitamin A deficiency might have in inhibiting proliferation of the spirochete in the host (Cantorna and Hayes, 1996; Carroll et al., 1996), the identification and characterization of numerous genospecies of *B. burgdorferi* (e.g., Magnarelli et al., 1995b; Mathiesen et al., 1997; Nakao et al., 1992; Oliver, 1996; Oliver et al., 1996; van Dam et al., 1997) as well as increased identification of ticks that harbor the *Borrelia* spirochete. The role that tick saliva plays in diminishing and impairing host initial inflammatory responses has been examined (Zeidner et al., 1996). Study of the role of plasmids in infectious strains of Lyme disease borreliae (Xu et al., 1996) may lead to information regarding infectivity of other spirochetes.

In contrast to the above proliferation of reports, research on *T. pallidum* has proceeded more slowly. For instance, Greenwood et al. (1992) reported that exposure at an early age to *T. pallidum* in rural Gambian women appeared to protect against birth defects associated with treponemal infection. Walker et al. (1991b) demonstrated by freeze fracture analysis that the outer membrane of *T. pallidum* contains rare surface-exposed intramembrane proteins. Subsequently, rare outer membrane, low-molecular mass proteins have been described (Stamm and Parrish, 1994). The role of macrophages in clearing *T. pallidum* from

infected tissue has been established and cytokine profiles have been described for syphilis infection (van Voorhis et al., 1996). The genome for *T. pallidum* subsp. *pallidum* has been described as a single, circular chromosome with a size of ~900 kilobase pairs (Walker et al., 1991a), highlighting its close relationship to *B. burgdorferi*, composed of one linear chromosome of ~950 kilobase pairs and multiple linear and circular plasmids (Johnson, 1993; Xu et al., 1996).

CONCLUSIONS

Caution is required in paleopathology. Thus, a conclusion of a "probable" case of prehistoric JRA was presented in Lewis (1994a,b). It was further suggested that what might be indicated for 16ST1-14883b is Lyme arthritis, a third or chronic stage expression of Lyme borreliosis. The juvenile form of arthritis associated with Lyme disease is subsumed under the subset of juvenile infectious arthritis, which itself is a category of juvenile chronic arthritis. Lyme arthritis is known to mimic pauciarticular JRA and polyarticular adult RA in its chronic expression. As more knowledge becomes available about the bony effects of Lyme arthritis, it is appropriate to keep in mind the possibility that the arthritic conditions evident in 16ST1-14883b may be related to the disease Lyme borreliosis. It is unfortunate that Rothschild and colleagues (1997) did not include in their detailed differential diagnosis a description of the skeletal pathological conditions associated with juvenile-onset Lyme disease as opposed to other expressions of juvenile chronic arthritis.

Lewis (1994a,b) also hypothesized that *B. burgdorferi* was the infectious agent responsible for adult forms of rheumatoid arthritis evident in prehistoric skeletal collections from the southeastern United States (e.g., Rothschild and Woods, 1991a; Rothschild et al., 1992). Both Hudson et al. (1975) and Rothschild et al. (1988) had previously predicted that an infectious agent was responsible for the prevalence of rheumatoid arthritis in these collections. Oliver (1996) provides a strong case for widespread distribution of *B. burgdorferi* in the southeast U.S. The role an iron-deficient environment has in the reduction of virulence of *B. burgdorferi* spirochetes (Carroll et al., 1996) has pertinence to the 16ST1 burial population, in which presence of iron deficiency anemia was discerned (Lewis, 1991b).

It is suggested here that juvenile-onset ankylosing spondylitis, a category of juvenile chronic arthritis (JCA), can probably, but not conclusively, be excluded as the cause of the skeletal pathological conditions evident in 16ST1-14883b based on patterns of joint involvement, absence of enthsities and syndesmophytes, and lack of involvement of the sacroiliac joint. Differential diagnosis indicates other forms of JCA, with the exception of Lyme arthritis and JRA, can also probably be excluded. If other researchers wish to exercise greater caution and refer to all these pathological conditions as JCA, the author has no problem with that preference. Whether JRA or JCA is the more appropriate designation, the hypothesis stated by Lewis (1994b) is independent of the designation preferred for skeletal pathological conditions evident in 16ST1-14883b and is still offered as a testable hypothesis to those interested in the history of disease and its capacity for informing on contemporary disease problems.

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